Collaborative Research: Impacts of Assimilating Remotely Sensed Snow on the Prediction of Orographic Precipitation and Streamflow in the Western United States

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*This report describes the portion of the work conducted/accomplished at the University of Pittsburgh. Progress made by L. Ruby Leung (PI) at PNNL, Battelle Pacific Northwest Division is reported separately.

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Report Figures:

Table 1. A list of different snow models that account for energy balance and their key features.

Snow models	Physical equations	Solar radiation penetration[5]	Water phases	Snow density (function of)	Liquid water treatment	Layers
BATS snow module (Simple)	Surface EB[1]	Not considered	Ice	Snow age	N/A	1 layer
VIC 2-L snow module (Simple)	EMB[2*]	Not considered	Liquid, ice	Snow age, compaction	Constant LWHC[3]	2 layers
NOHRSC snow model (Medium)	EMB	N/A	Liquid, ice	Mass balance, compaction	Constant LWHC[3]	3 layers
Lynch-Stieglitz model (Medium)	EMB	Not considered	Liquid, ice	Snow age	Constant LWHC[3]	3 layers
SAST snow model (Medium)	EMB, W/IVD	Considered	Liquid, ice	Mass balance, compaction	Function of snow density	3 layers
CLM snow model (Complex)	EMB	Not considered	Liquid, ice	Mass balance, compaction	Function of fixed irreducible water	M-L[4]
VIC M-L snow module (Complex)	EMB, W/IVD	Considered	Liquid, ice	Mass balance, compaction	Function of snow density	M-L
SNTHERM (Very Complex)	EMB	Considered	Liquid, ice, vapor	Mass balance, compaction	Gravitational flow	M-L
Anderson snow model (Very Complex)	EMB	Considered	Liquid, ice, vapor	Mass balance, compaction	Function of snow density	M-L

[1] EB: energy balance
[2] EMB : energy mass balance
[3] LWHC: liquid water holding capacity
[4] M-L: multilayers, more than 3 layers
[5] penetration into intermediate snow layer
[6] W/IVD: with indirect consideration of vapor diffusion within conductivity
* Excessive energy at the surface transferred to the lower layer

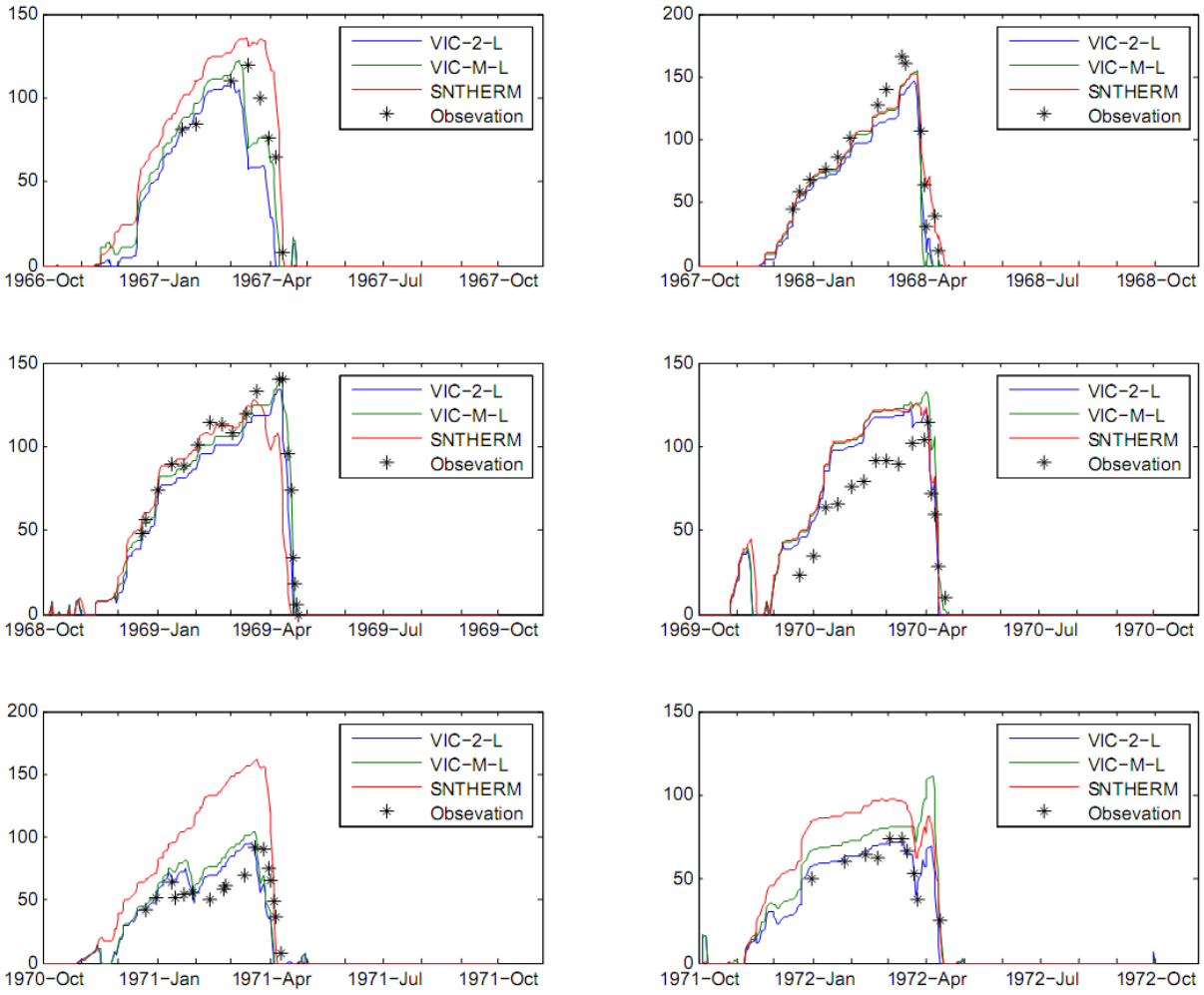

Figure 1a. Comparison of SWE between VIC-2L, VIC-ML, and SNTHERM for the period from 1966 – 1977 at the Valdai site in Russia which has a shallow snowpack. The albedo for SNTHERM is set to be 0.54, while the albedo for VIC-2L and VIC-3L is calculated automatically by each model.

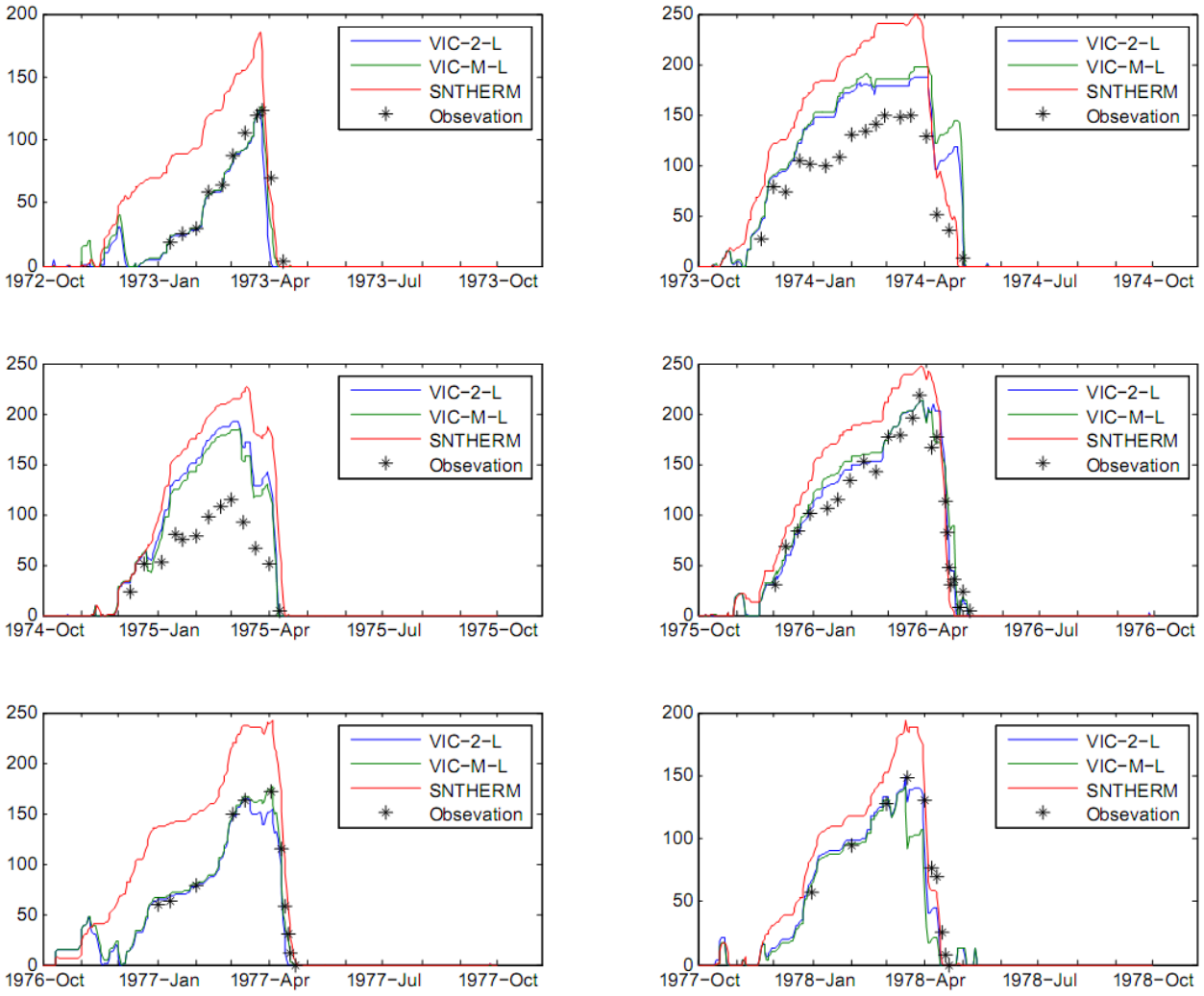

Figure 1b. The same as Figure 1a, but for the period from 1973 – 1987.

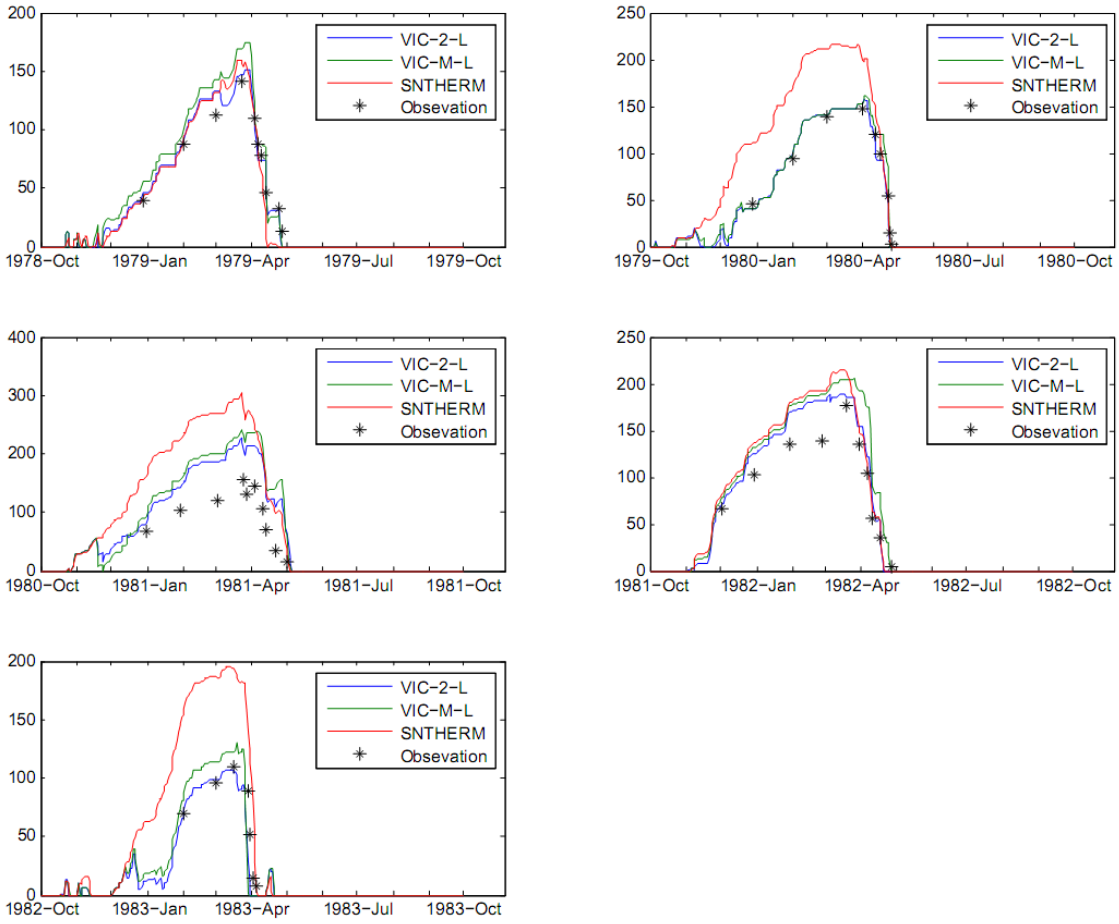

Figure 1c. The same as Figure 1a, but for the period from 1979 – 1983.

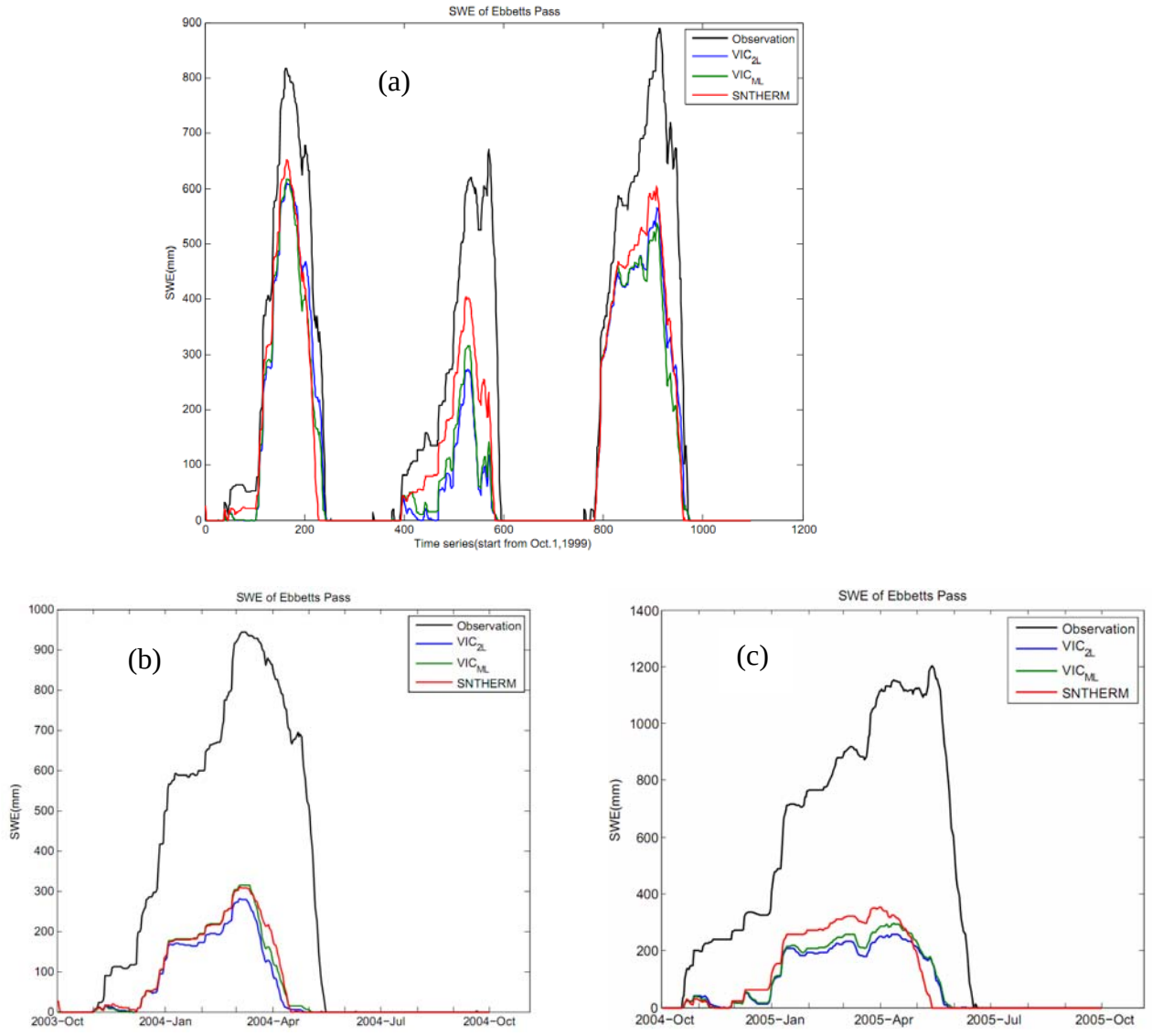

Figure 2. Comparison of SWE between VIC-2L, VIC-ML, and SNTHERM for the period from 1999 – 2005 at the Ebbetts Pass site in California which has a moderate snowpack. The albedo for SNTHERM is set to be 0.67, while the albedo for VIC-2L and VIC-3L is calculated automatically by each model. (a) from 1999 – 2002, (b) from 2003 – 2004, and (c) from 2004 – 2005.

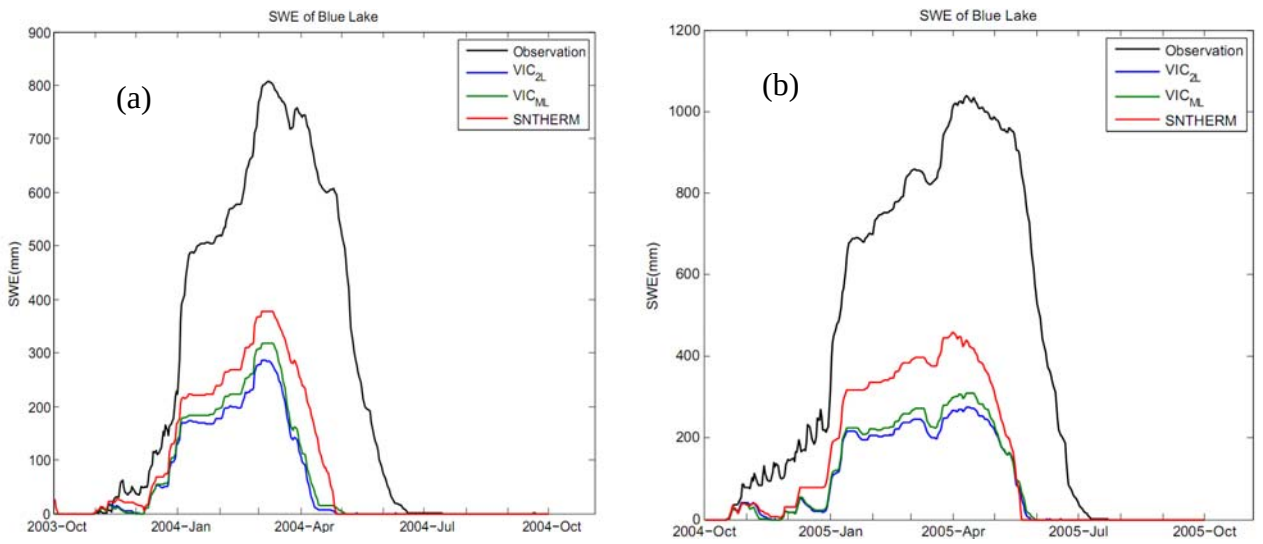

Figure 3. Comparison of SWE between VIC-2L, VIC-ML, and SNTHERM for the period from 2003 – 2005 at the Blue Lake site in California which has a moderate snowpack. The albedo for SNTHERM is set to be 0.69, while the albedo for VIC-2L and VIC-3L is calculated automatically by each model. (a) from 2003 – 2004, and (b) from 2004 – 2005.

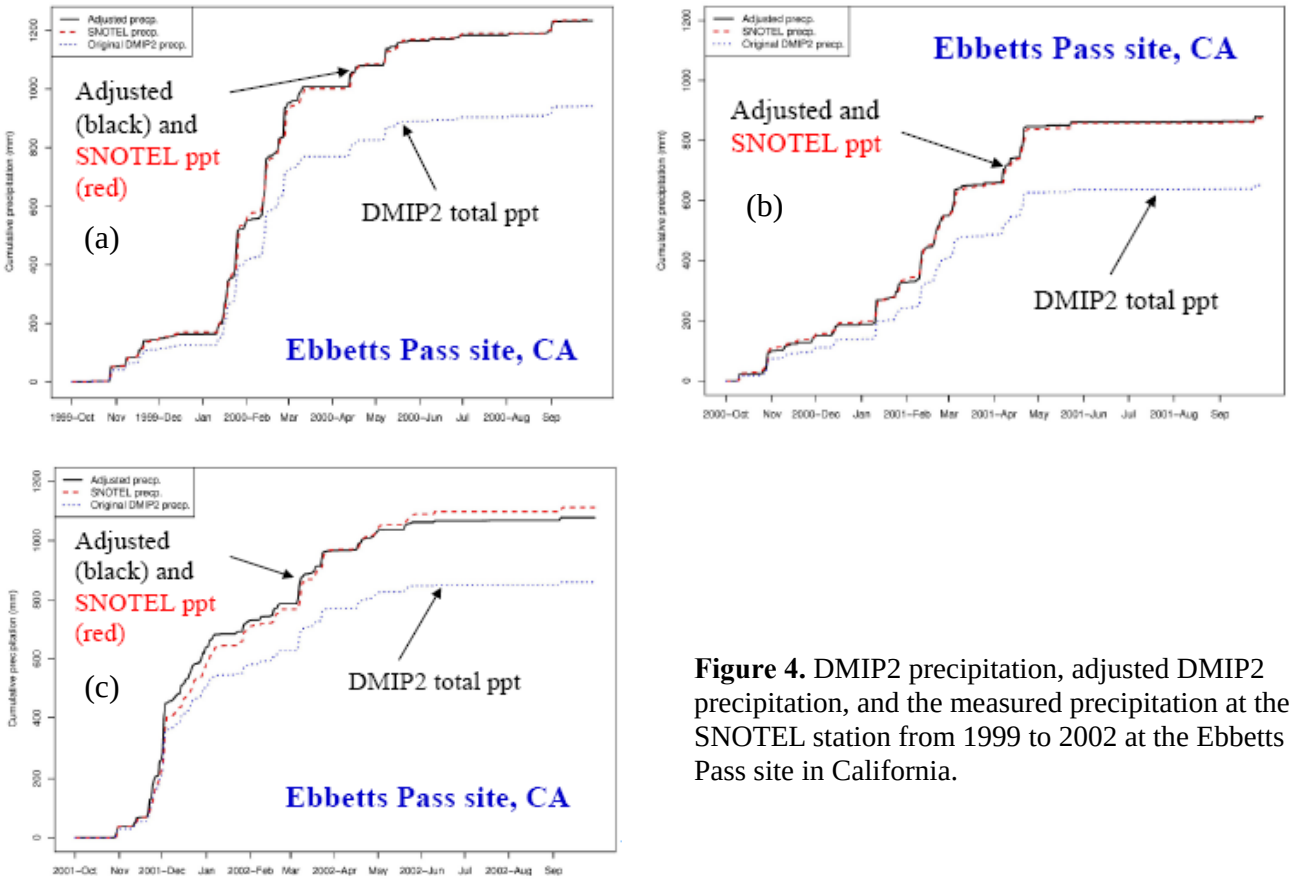

Figure 4. DMIP2 precipitation, adjusted DMIP2 precipitation, and the measured precipitation at the SNOTEL station from 1999 to 2002 at the Ebbetts Pass site in California.

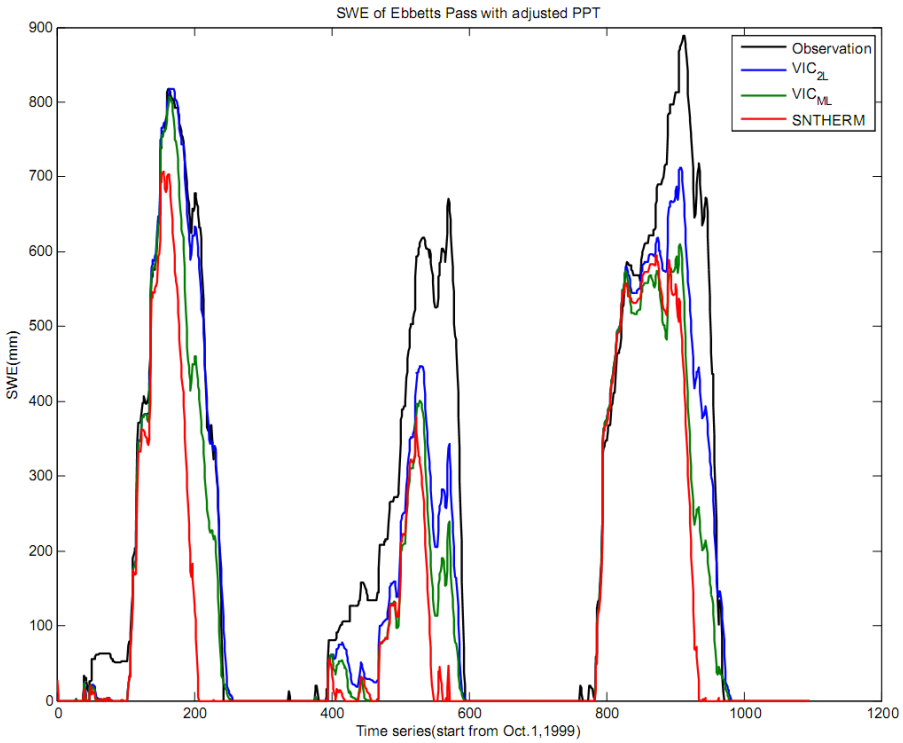

Figure 5. Comparison of SWE between VIC-2L, VIC-ML, and SNTHERM for the period from 1999 – 2005 at the Ebbetts Pass site in California with adjusted DMIP2 precipitation shown in Figure 4. The albedo for SNTHERM is set to be 0.54 as opposed to 0.67 shown in Figure 2a. The albedo for VIC-2L and VIC-3L is calculated automatically by each model.

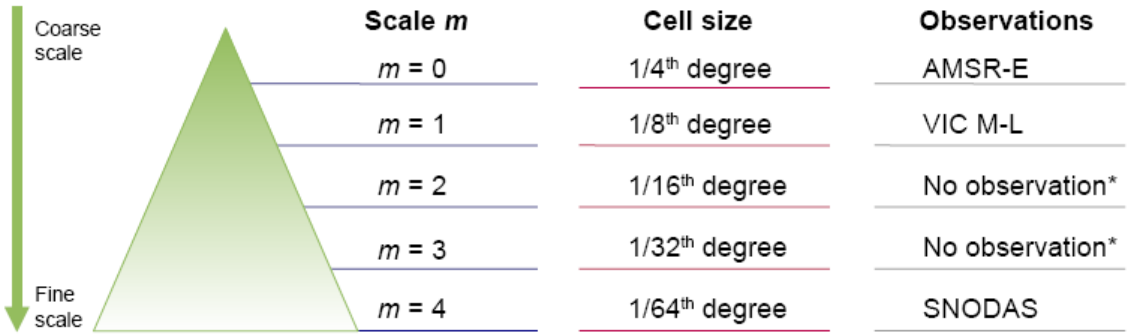

Figure 6. Schematic of the relevant spatial scales, their corresponding cell sizes/resolutions, and data used.

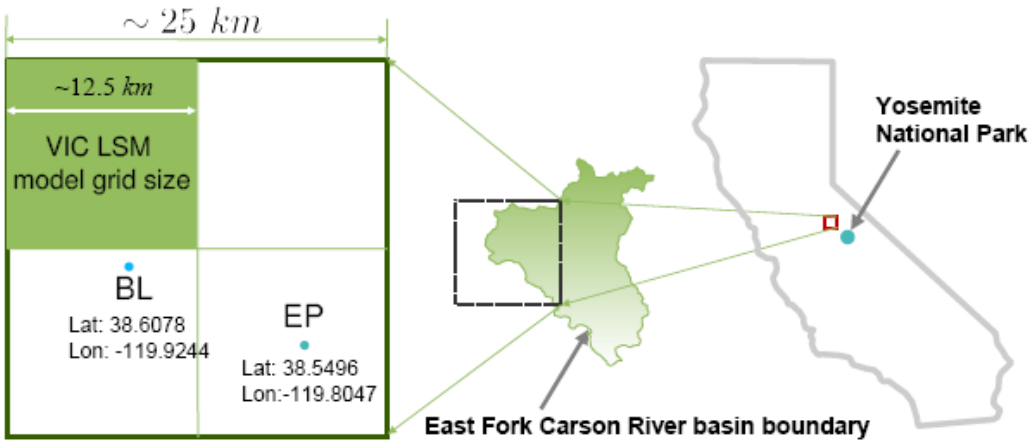

Figure 7. The 25 km × 25 km study domain and their relative locations in California.

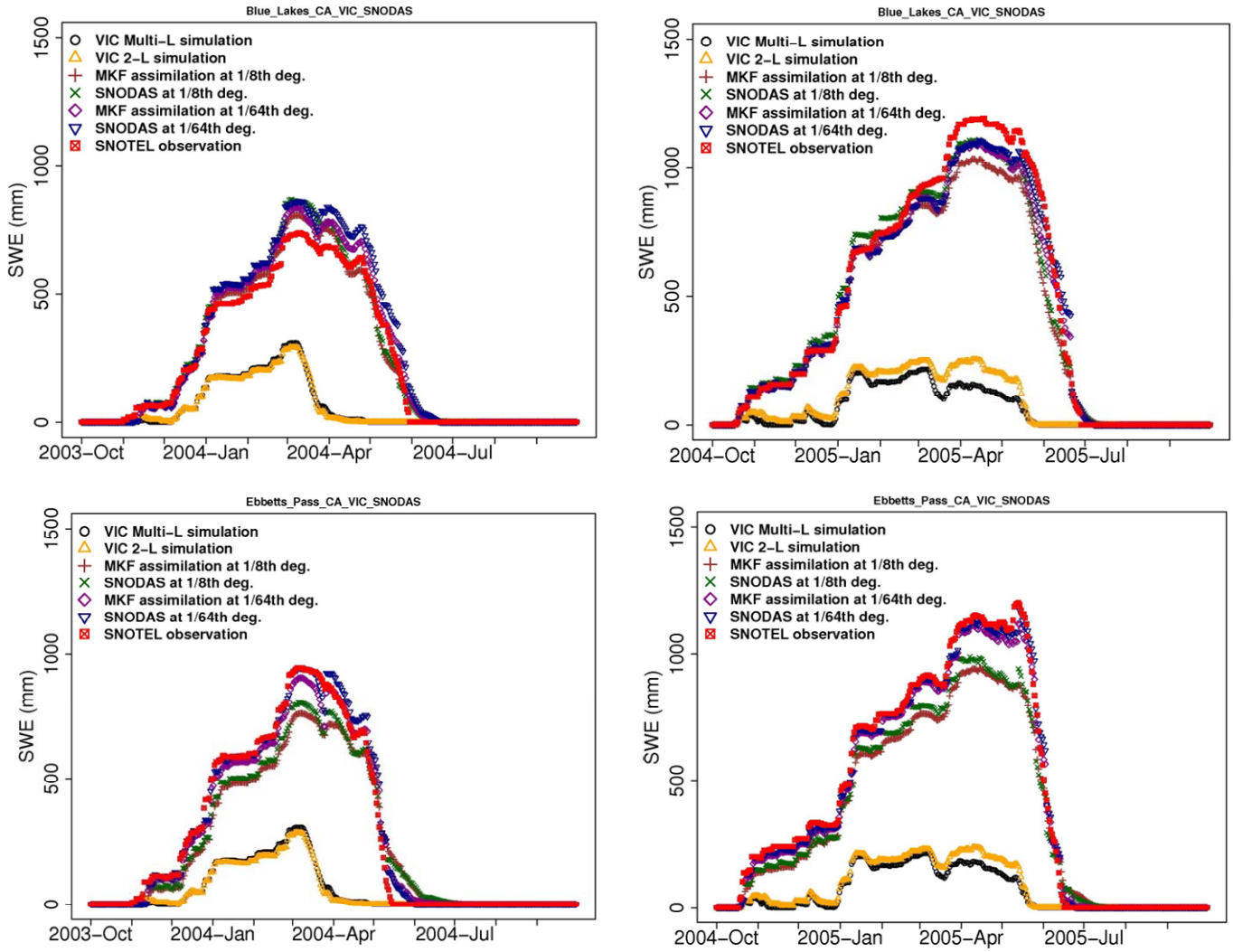

Figure 8. Assimilation results with SNODAS at grid cells including the Blue Lakes (top) and Ebbetts Pass (bottom) SNOTEL stations.

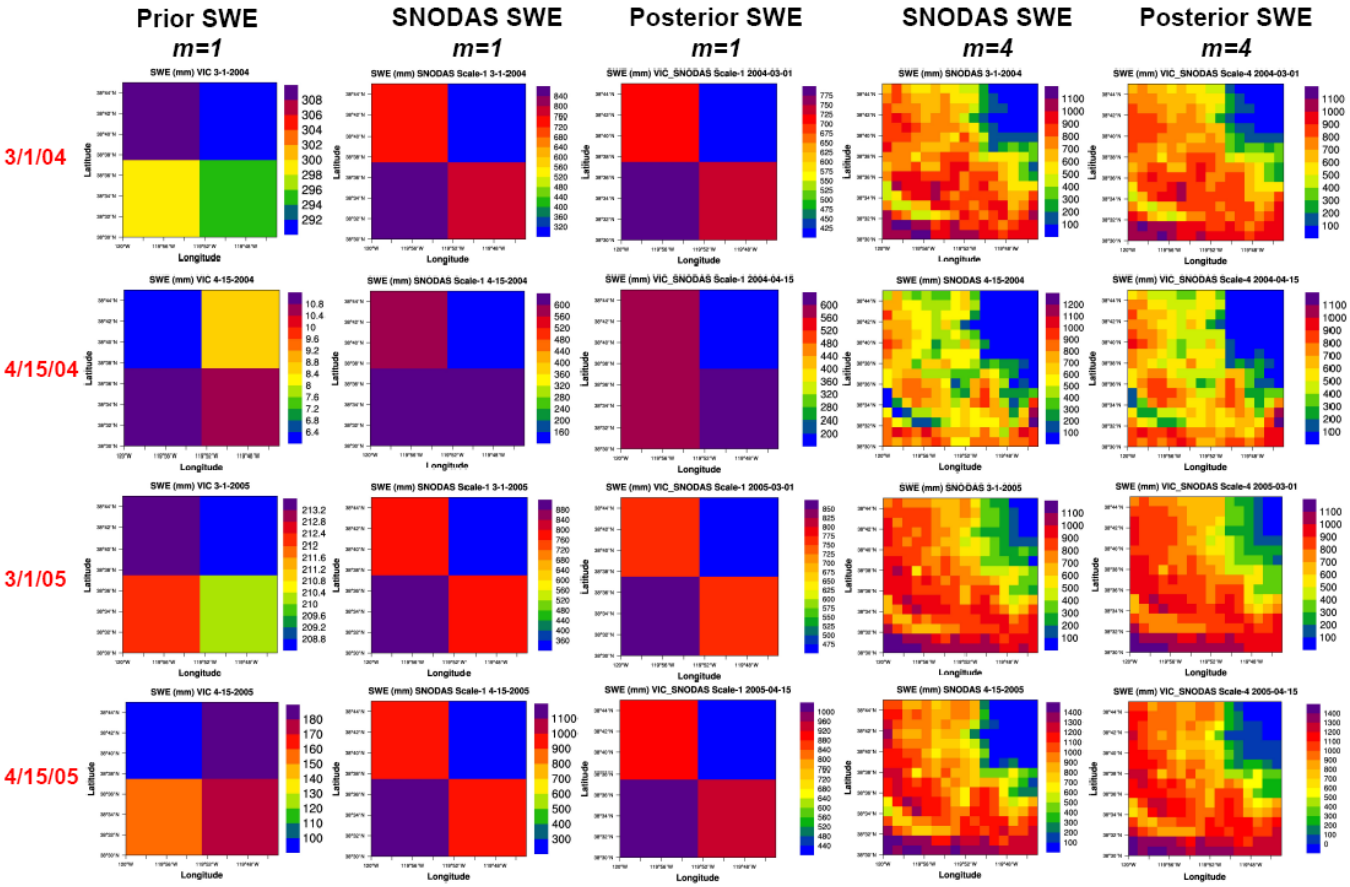

Figure 9. Assimilation results with SNODAS data at different scales (only results with m = 1 and m = 4 are shown). SNODAS SWE denotes the SWE retrieved from SNODAS at a given scale m, Prior SWE VIC M-L snow model prediction for the current time given previous assimilations at scale m = 1 and, Posterior SWE the assimilation results for the current time step at a given scale , which belongs to {0, 1, 2, 3, 4} in this experiment.

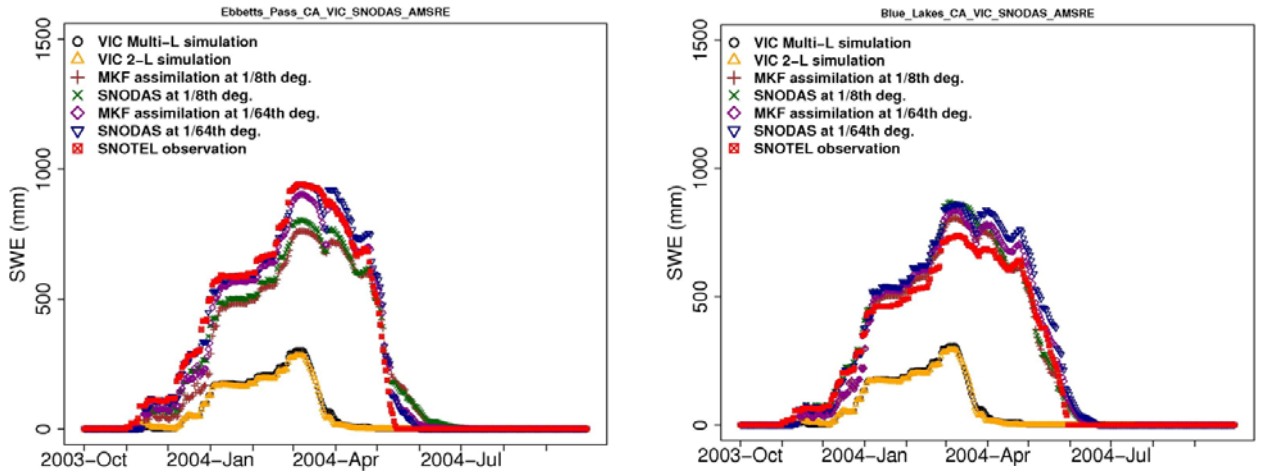

Figure 10. Assimilation results with SNODAS and AMSR-E at grid cells including the Ebbetts Pass (left) and Blue Lakes (right) stations.

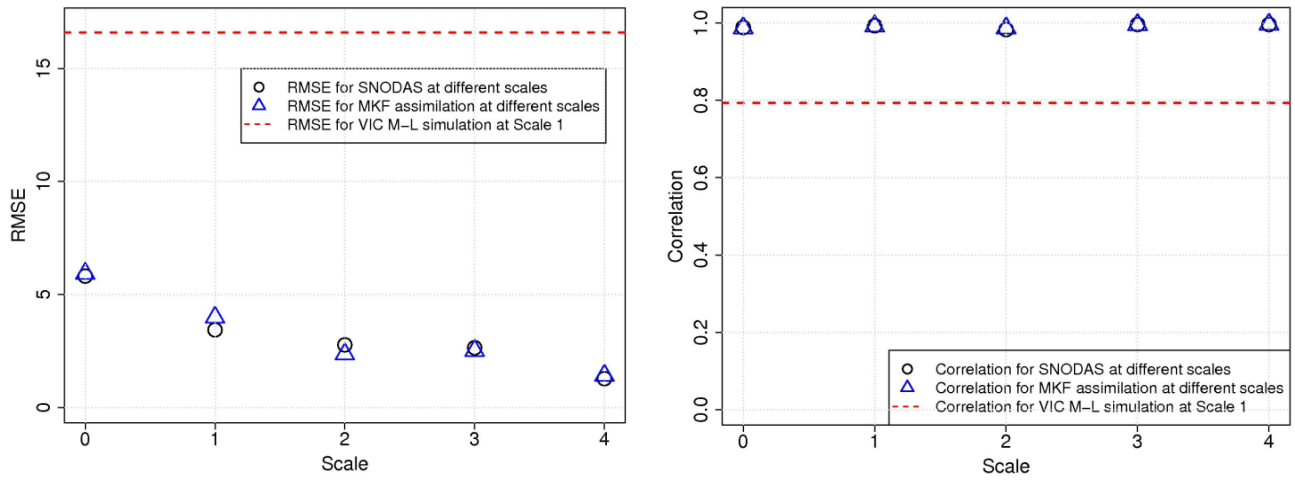

Figure 11. Root mean square error (RMSE) and correlation at different scales. In both plots, the reference data are SNOTEL observations at the Ebbetts Pass station.